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Technical Matters

Contractual Matters (thru OCA)

Ms. Susan Chochoms
Naval Underwater Systems Center
New London Laboratory
New London, CT 06320
Phone: (203)442-0771, x2339

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32

# GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

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Project No: A-2242

Project Director: Mr. E. F. Knott

Sponsor: Naval Underwater Systems Center; New London Laboratory; New London, CT 06320

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A-2242

# Literature Search on Electromagnetic Propagation

by
Eugene F. Knott

Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

Prepared for the Naval Underwater Systems Center
New London, Connecticut 06320

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TABLE OF CONTENTS

## FORWARD

This report was prepared under Requisition N66604-8240-1081 and is submitted as Data Item A001 of the Contract Data Requirement List of that Requisition. The literature search was performed during November and December 1978.

# I. INTRODUCTION

This report is a summary of references identified in a literature search for information on electromagnetic propagation. The search revealed a great deal of prior work in propagation effects and the task is more one of sifting existing data and extracting useful results than of locating adequate sources of information. The references include papers published in professional journals, several texts, U. S. Government publications and the proceedings of the International Radio Consultative Committee (CCIR). There also exists a considerable body of meteorological information useful for testing the sensitivity of propagation models to climatic conditions. Much of these data were collected under the control of, or for use within, the Navy and therefore ought to be easily available.

# II. PROPAGATION PHYSICS

There are four basic mechanisms by which EM waves propagate from one point to another near the earth's surface:

1. diffraction
2. reflection from the ionosphere
3. refraction occuring within the atmosphere
4. surface wave propagation along a dielectric interface

Diffraction is the phenomenon in which the direction of propagation and the intensity of a wave are changed due to the presence of an obstacle, and in the case at hand, the obstacle is the earth itself. A formal mathematical statement can be made about diffraction by a sphere but the computation of the total field intensity at an arbitrary point using this formalism is useless for a sphere more than a few hundred wavelengths in diameter. However, empirical relations exist that have been in use with confidence for many years. The concept of diffraction loses much of its importance above 30 kHz or so, and is thus associated primarily with low frequency ground waves.

Although surface wave propagation is a form of diffraction, this means of propagation is regarded as a kind of guide wave, in which the wave energy tends to be concentrated near the earth's surface. The characteristics of the surface wave depend on its frequency and the nature of the surface (i.e., propagating over land or water). The surface wave decays in amplitude because of energy losses attributable to the surface as well as the more familiar spreading away from the source. Surface losses are due to actual propagation of energy into the ground and the incident phase fronts are angled slightly away from the vertical. These waves lose importance above 30 MHz or so due to the rapid attenuation with higher frequency, increased losses and greater distances.

Electromagnetic signal can also be reflected by the ionosphere if the frequency is low enough, consequently there are points on the earth's surface where reception is poor because of the unfavorable geometry of the ray path. The "skip distance" obviously depends on the effective height of the reflecting layer, and in fact whether the layer even exists. Since the tenuous gases constituting these layers require the ionizing influence of solar radiation, one of the layers tend to disappear at night. Moreover, the sky wave and ground wave may both be present at some frequencies and distances and at times tend to cancel or reinforce each other depending on their relative phase angle at the point of reception.

The sky waves owes its usefulness to the presence of the ionosphere, whose refractive index depends on the degree of ionization and the frequency of the wave. The effective properties as "seen" by an incident wave depend on whether the wave frequency is above or below the plasma frequency, which in turn depends on the temperature and electron density of the ionosphere. These, in turn, are related to the amount of solar radiation impinging on the ionosphere, which is obviously quite different from night to day. Sky wave propagation therefore exhibits diurnal variations as well as a dependence on frequency.

Atmospheric refraction occurs at all frequencies but is more important in the microwave and optical regions than at lower frequencies because of the much greater electrical path lengths (path lengths measured in wavelengths). The index of refraction generally decreases with increasing height, consequently EM propagation paths tend to be bent downward. Under normal conditions the amount of bending is much less than the radius of the earth and ray paths appear to be bent upward to an observer on the earth's surface. In many cases it is convenient to regard the earth as a flat surface and in order to preserve the apparent relative geometry of the ray paths and the earth's surface, it is necesary to assign an additional curvature to the ray paths. This may be done by adding a height-dependent term to the index of refraction, with the result that the modified index increases with altitude instead of decreasing.

Over the ocean surface it is not uncommon for the refractive index to decrease more rapidly with height than the additive term, primarily due to temperature inversions and decreasing humidity. In this case, a "duct" is formed within which the propagation paths are bent sharply downward and if the curvature is small enough, the ray path will intercept the ocean surface or the bottom of the duct where it will be reflected upward again, only to be bent down again as the wave propagates. Depending on meteorological conditions, the duct may be formed at the ocean surface or it may occur at altitudes of several thousands of feet.

At low frequencies the gradient in the atmospheric refractive index has very little influence and propagation losses may be estimated on the basis of the constants of the surface over which the ground wave propagates and on the reflective properties of the ionosphere for the sky wave. The ground wave path loss increases with increasing frequency and decreasing ground conductivity. Propagation over sea water can be 10 to 40 dB better than over land, depending on frequency and distance. Ground wave propagation becomes essentially useless for ranges more than 20 miles at 10 mHz or so, and point-to-point transmission is possible only by means of the sky wave for much longer distances. Vertical polarization propagates far better than horizontal because the transverse electric field at the ground surface must be small (zero for perfectly conducting surface) in order to satisfy the boundary conditions. At these frequencies even a tall vertical mast may be only a fraction of a wavelength in height.

Due to the presence of free electrons in the ionosphere, the index of refraction can be less than that of free space, and, depending on the frequency of the incident wave, can even be negative. The precise characteristics of the ionosphere vary with height because a "critical" frequency exists that depends on the electron density. Both the refractive index and the conductivity of the ionosphere depend on the critical frequency, the electron collision frequency and the frequency of the incident wave.

Since the amount of bending of a ray in entering the ionosphere depends on the angle of incidence, some waves are bent (refracted) more than others; it is possible for the ray to pass through and never return to the earth if the angle of arrival is small enough, as measured from the local vertical. The critical angle depends on frequency via the explicit dependence of the refractive index on frequency. Consequently the ionosphere is generally a refracting medium instead of a reflecting one, although reflective concepts are often applied in estimating the ray paths.

The reflection of sky waves from the ionosphere makes long-distance communication possible via a sequency of skips. Since the skip distance is a function of the effective height of the reflecting surface, it is possible that intermediate points on the ground may not lie at the proper distance for proper reception. This is why a close receiver may often be unable to detect a signal while a much more distant receiver can.

Normal operation of communication links is helped by the selection of the lower and upper frequencies by a graphical procedure or by means of computer-assisted models. The maximum useable frequency is a function of the transmission distance and the vertical ionization distribution and the lowest useful frequency depends on such factors as the directivity of the transmitting and receiving antennas, and the presence of atmospheric noise, which is a common limitation. These frequency limits change during the day as well as from season to season. The critical plasma frequency also depends on latitude. The Environmental Sciences Services Administration (ESSA) publishes monthly predictions of optimum working frequencies and forecasts of ionospheric disturbances.

Propagation in these frequencies ranges obviously depends upon a knowledge of how the ionosphere behaves from day to day, year to year and season to season.

Sunspot activity is very important in influencing the properties of the ionosphere and atmospheric radio noise, and the 11-year cycle should be accounted for in predictions. Thus, in contrast to microwave frequencies, propagation below about 30 mHz is essentially independent of weather conditions, but highly dependent on the state of the ionosphere. Other factors influencing propagation are atmospheric absorption due to water vapor and oxygen. This absorption is significant only at millimeter and infrared wavelengths and is due to the permanent dipole moment of the molecules of these gases.

Rainfall and fog are other factors influencing propagation both at radar frequencies and optical wavelengths. Such conditions can be relatively short term and on a seasonal or annual basis may be negligible. The attenuation due to rainfall depends on the droplet size, the wavelengths and on the rate of precipitation, and models for the attenuation are based on the scattering properties of dielectric spheres. Unfortunately it is difficult to set up controlled experiments for rainfall to verify the models.

There are more than 40 important operating areas in the world and these will be reduced in number as much as possible, probably six or fewer. The primary distinction between these areas, insofar as the importance of EM propagation is concerned, is latitude, although some variations due to longitude of proximity to land masses may be expected. The operating areas may be categorized as follows:

1. Subpolar: 50 to 70 degrees latitude
2. Temperature; 25 to 50 degrees latitude
3. Tropical; 0 to 25 degrees latitude

Each operating area may be associated with the maintime conditions of the open sea or with coastal regions in each latitude, thereby forming a matrix of six types of operating areas. Two of three additional classes of operating area may have to be added to the list to account for unusual climatic conditions perculiar to specific areas.

The atmospheric index of refraction is a function of height and depends on the absolute temperature of the air and the partial pressures of dry air and water vapor. Consequently one must have a knowledge or an estimate of these meteorological parameters as functions of height in order to predict propagation effects at centimeter and millimeter wavelengths. Unfortunately, not all of the data necessary for statistical studies of their effects are available.

## III. REFERENCES

### A. Assorted Propagation References

Of the many studies of propagation made over the years, the following list of references is a sampling. Some are theoretical, some experimental, while others merely describe propagation effects without presenting mathematical relations.

Five of them are particularly useful. Bremmer [2] treats the propagation problem fairly rigorously and in detail commencing with a simple approach ignoring the ionosphere and atmospheric refraction and ending with a complete treatment that even includes the effects of the earth's magnetic field. Budden's book [3] is quite analytical and treats sound waves as well as electromagnetic waves. Davies' work [7] is mathematically fairly simple, but covers a large variety of propagation effects. Norton [19] is also mathematically simple, but contains many useful tables and charts, covering a wide range of frequencies and propagation circumstances.

Wait's book [22] is quite analytical, like Bremmer's, and emphasizes VLF and ELF applications.

Others may not be as useful, but may contribute insight not always present in very detailed mathematical treatments. Examples are Johler [15], Watt [23] and the IRE publication [24]. Many of the remaining references are not particularly useful, and some have not been located within the Georgia Tech library system, but are included as possible sources for further references.

Assorted Propagation References:


1. B. R. Bean and E. J. Dutton, "Radio Meteorology," Monograph 92, Institute of Telecommunications Sciences and Aeronomy, Environmental Science Services Administration (ESSA), Superintendent of Documents, Washington, D.C.; 1966

2. H. Bremmer, Terrestrial Radio Waves, Elsevier Publishing Co., Inc., New York; 1949

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6. B. Cooper, "Optical Communications in the Earth's Atmosphere," IEEE Spectrum, pp. 83-88; July 1966

7. K. Davies, "Ionospheric Radio Propagation," Monograph 80, National Bureau of Standards, Washington, D.C.; 7 April 1965

8. S. Glasstone, "The Effects of Nuclear Weapons," U. S. Government Printing Office, Washington, D.C.; 1962

9. G. L. Grisdale, J. H. Mouiss and D. S. Palmer, "Fading of Long-Distance Radio Signals and a Comparison and Space and Polarization Diversity Reception in the 6-18 Mc Range," Proceedings of the IEE, (London), Part B, No. 13, pp. 39-51; January 1957

10. D. R. Hansen and C. O. Hines, "The Principles of JANET-A Meteor Burst Communication System," Proceedings of the IRE, Vol. 45, pp. 1642-1657; December 1957

11. A. F. Harvey, Microwave Engineering, Academic Press, New York; 1963

12. H. V. Hitney and J. H. Richter, "Integrated Refractive Effects Prediction Systems (IREPS)," URSI Commission F Presentation at La Baule, France; 28 April - 6 May, 1977

13. J. N. Howard, "The Transmission of the Atmosphere in the Infrared," Proceedings of the IRE, Vol. 47, No. 9, pp. 1451-1457; 1959

14. H. B. James, J. T. Collins, and E. K. Steele, "A Preliminary Catalog of Programs and Data for 10-100 GHz Radio System Predictions," U. S. Department of Commerce Report UTREPORT 78-141; March 1978

15. J. R. Johler, "Propagation of the Low-Frequency Radio Signal," Proceedings of the IRE, Vol. 50, No. 4, pp. 404-427; 1962

16. D. E. Kerr, "Propagation of Short Radio Waves," McGraw-Hill, New York; 1951 (Vol. 13 of the MIT Rad Lab Series)

17. D. L. Lucas and G. W. Haydon, "Predicting Statistical Performance Indexes for High-Freqnecy Ionospheric Telecommunications Systems," ESSA Tech. Dept. IERl-ITSA: August 1966

18. D. G. C. Luck, "Some Factors Affecting Applicability of Optical-Band Radio (Coherent Light) to Communication," RCA Review, pp. 359-409; September 1961

19. K. A. Norton, "Transmission Loss in Radio Propagation: II." National Bureau of Standards Technical Note 12; June 1959

20. K. W. Pearson, "Method for the Prediction of the Fading Performance of a Multi-Section Microwave Link," Proceedings of the IEE (London). Vol. 112, No. 7, pp. 1291-1300; July 1965

21. R. K. Salaman, "A New Ionospheric Multipath Reduction Factor (MRF)," IRE Transactions on Communications Systems, Vol. C5-10, pp. 220-222; June 1962

22. J. R. Wait, "Electromagnetic Waves in Stratified Media," Pergammon Press, Long Island City, New York; 1962

23. A. D. Watt, "VLF Radio Engineering," Vol. 14, International Service of Monographs in Electromagnetic Waves, Pergammon Press, New York; 1967

24. "Ionospheric Scatter Transmission," Proceedings of the IRE, Vol. 48, No. 1, pp. 5-29; 1960

## B. The CCIR references

CCIR is the acronym for the International Radio Consultative Committee. It meets periodically and makes recommendations on frequency standards, propagation models, and a variety of topics of interest to the communications and radar world. Study groups examine all phases of radio problems and the results and recommendations are published for the benefit of all who work in this area. Three Plenary Assemblies have been held (Oslo, 1966; New Delhi, 1970; Geneva, 1974) and the listing below is a selection of pertinent report titles from the 1974 Assembly.

CCIR

Reports in Volume V of the CCIR Thirteenth Plenery Assembly, Geneva, 1974

| Report | |
|---|---|
| 229-2 | Electrical characteristics of the surface of the Earth |
| 233-3 | Influence of the non-ionized atmosphere on wave propagation. (Ground-ground propagation) |
| 234-3 | Influence of the non-ionized atmosphere on wave propagation. (Earth-space propagation) |
| 235-2 | Effects of tropospheric refraction at frequencies below 10 MHz |
| 238-2 | Propagation data required for trans-horizon radio-relay systems |
| 239-2 | Propagation statistics required for broadcasting services, using the frequency range 20 to 1000 MHz |
| 338-2 | Propagation data required for line-of-sight radio-relay systems |
| 424-1 | VHF, UHF and SHF propagation curves for the aeronautical mobile service |
| 425-1 | Estimation of tropheric-wave transmission loss. (Availability of computer methods and preparation of propagation curves for broadcast and mobile services.) |
| 428-1 | The computation of ground-wave propagation curves |
| 562 | Propagation data required for sound and television broadcasting in the frequency bands above 10 GHz. (Terrestrial broadcasting at 12 GHz) |
| 563 | Radiometeorological data |
| 564 | Propagation data required for space telecommunication systems |
| 565 | Propagation data for broadcasting from satellites at frequencies above 10 GHz |
| 566 | Free-space propagation |
| 251-1 | Intermittent communication by meteor-burst propagation |

CCIR

Reports in Volume VI of the CCIR Thirteenth Plenary Assembly, Geneva, 1974

| | |
|---|---|
| 255-3 | Basic prediction information for ionospheric propagation |
| 256-2 | Maximum transmission frequencies |
| 258-2 | Man-made radio noise |
| 259-3 | VHF propagation by regular layers, sporadic E or other anomalous ionization |
| 260-2 | Ionospheric-scatter propagation |
| 262-3 | VLF propagation in and through the ionosphere |
| 263-3 | Ionospheric-scatter propagation |
| 264-3 | Sky-wave propagation curves between 300 km and 3500 km at frequencies between 150 kHz and 1600 kHz in the European Broadcasting Area |
| 265-3 | Sky-wave propagation at frequencies below 150 kHz with particular emphasis on ionospheric effects |
| 341-2 | HF propagation by ducting above the maximum of the F region |
| 343-2 | Radio noise within and above the ionosphere |
| 431-1 | Analysis of sky-wave propagation measurements for the frequency range 150 kHz to 1600 kHz |
| 432 | The accuracy of predictions of sky-wave field strength in bands 5 (LF) and 6 (MF) |
| 571 | Comparisons between observed and predicted sky-wave field strength and transmission loss at frequencies between 2 and 30 MHz |
| 572 | Estimation of sky-wave field strength and transmission loss at frequencies between 2 and 30 MHz (A proposed plan for revision of the C.C.I.R. interim method) |
| 573 | The characteristics of sporadic E |
| 575 | Methods for predicting sky-wave field strengths at frequencies between 150 kHz and 1600 kHz |

C. Sources of Meteorological Data

Four distinct sources of meteorological data have been pointed out by the U. S. Climatic Center. These are

1. Synoptic Meterological Observations
2. Marine Climatic Atlas
3. A through F Summaries
4. Radiosonde Summaries

The synoptic obervations cover nearly all the operational areas of the world and are available from the National Technical Information Service (NTIS). Typical synoptic data are presented in tabular form (a total of 21 tables) and contain such information as the percentage frequencies of:

Sky obscured (by low clouds)

Wind direction

Relative humidity by air temperature

Surface wind speed and direction

Wave height vs wave period

Other tables include

Means, extremes and percentiles of air temperature

Monthly and annual means of sea surface temperature

Monthly and annual mean sea level pressure

Unfortunately, these data do not necessarily give the information necessary to construct vertical profiles of the atmospheric under refraction.

The marine climate atlas contains data that were generated almost exclusively within the Navy, and much of the data are side in Naval publications and documents. Climatic data cover broad areas, such as the North Atlantic, South Atlantic, North Pacific, South Pacific, Indian, Arctic and Antarctic Oceans. Some of the data include upper wind statistics charts, 1000 millibar winds and selected level, heights, temperatures and dew points for the northern hemisphere. There are also special marine environmental studies covering U. S. coastal areas as well as northern environmental scenarios.

The A through F summaries are NAVAIR documents for specific stations and contain data on ceiling, visibility, winds and psychrometric data. (The latter is used to generate humidity data.) The radiosonde summary, prepared by the Air Weather Services, gives temperature, relative humidity and winds as a function of height, and the data are available on a station-by-station basis. However, these profiles may be restricted in height (200 meters) and the stations are primarily fixed land stations which may not neccessarily generate useful data for marine applications.

| Summary of Synoptic Meteorological Observations | | Vol. No. | Accession No. |
|---|---|---|---|
| EAST AFRICAN AND SELECTED ISLAND COASTAL MARINE AREAS | | | |
| Areas 1-6 | Kuria Muria Is, W Arabian Sea, Qamr Bay, Socotra Is, Gulf of Aden NE, NW | 1 | AD 780 313 |
| 7-12 | Red Sea S, S Central, Central, North, North Central, Gulf of Suez | 2 | AD 780 662 |
| 13-18 | Gulf of Aden, SW, SE, Somali Coast NE, E, SE, S | 3 | AD 780 314 |
| 19-25 | Kenya Coast, Zanzibar, Tanzania Coast SE, Porto Amelia, Lumbo, Mozambique Channel NW, SW | 4 | AD 780 667 |
| 26-32 | Lourenco Marques, Tulear, Mozambique Channel SE, NE, Diego Garcia, Gan, Minicoy Is | 5 | AD 780 670 |
| SOUTHWEST ASIAN COASTAL MARINE AREAS | | | |
| Areas 1-4 | Akyab, Calcutta, Vishakhapatnam, Masulipatam | 1 | AD 747 638 |
| 5-8 | Madras, NE-SE-W Ceylon | 2 | AD 736 449 |
| 9-12 | Cape Comorin, Mangalore, Panjim, Bombay | 3 | AD 735 441 |
| 13-16 | Gulf of Cambay, NE-NW Arabian Sea, SE Oman | 4 | AD 734 150 |
| 17-20 | Karachi, Sonmiani, Gwadar, N Gulf of Oman | 5 | AD 733 693 |
| 21-24 | S Gulf of Oman, SE-NE-NW Persian Gulf | 6 | AD 737 909 |
| SOUTHEAST ASIAN COASTAL MARINE AREAS | | | |
| Areas 1-4 | Tonkin Gulf, Da Nang, Nha Trang, Saigon | 1 | AD 733 692 |
| 5-7 | Southeast Gulf of Siam, North, SW Gulf of Siam | 2 | AD 749 936 |
| 8-11 | Kuala Trengganu, Endau, S-N Malacca Strait | 3 | AD 749 937 |
| 12-14 | Victoria Point, Rangoon, Pagoda Point | 4 | AD 750 159 |
| INDONESIAN COASTAL MARINE AREAS | | | |
| Areas 1-7 | SE Sumatra, Christmas I, Sunda Strait, NW Java Sea, Bangka Is NW, Natuna I, Sarawak | 1 | AD-A006 923 |
| 8-14 | W Borneo, Karimata Strait, SW Java Sea-SE, NE; S Central Java, Southeast Java | 2 | AD-A007 969 |
| 15-21 | Bali Sea, Flores Sea-NW, S Makassar Strait-Central North, Southwest Celebes Sea | 3 | AD-A009 275 |
| 22-28 | Northwest Celebes-E, Northeast Molucca Sea, SE; Northeast Banda Sea, Timor NW, North Timor Sea | 4 | AD-A009 276 |
| 29-34 | Melville I, West Arafura Sea-E, West Torres Strait-E, Gulf of Papua SE | 5 | AD-A009 648 |
| 35-40 | SE New Guinea, Northwest Solomon Sea, N, SE Admiralty Is East, New Ireland Northeast | 6 | AD-A009 965 |
| AUSTRALIAN COASTAL MARINE AREAS | | | |
| Areas 1-8 | Princess Charlotte Bay, Cairns, Cumberland Islands, Rockhampton, Brisband, Coffs Harbour, Sydney, Cape Howe NE | 1 | AD-A044518 |
| 9-15 | Melbourne SE, Tasmania E, W. Cape Nelson, Spencer Gulf, Australian Bight, SE, SW | 2 | AD-A044426 |
| 16-22 | Esperance Bay S, Cape Leeuwin, Perth NW, Shark Bay, Barrow Island, Broome, Cape Talbot | 3 | AD-A044425 |

| Summary of Synoptic Meteorological Observations | | | Vol. No. | Accession No. |
|---|---|---|---|---|
| CHINESE-PHILIPPINE COASTAL MARINE AREAS | | | | |
| Areas | 1-4 | Gulf of Chihli, Tsingtao, Yellow Sea SW, Shanghai | 1 | AD 758 372 |
| | 5-8 | Wenchow, Taiwan E, W, Swatow | 2 | AD 760 333 |
| | 9-12 | Hong Kong, Luzon NE, Luzon NW, Hainan SE | 3 | AD 762 423 |
| | 13-16 | Luzon SE, Manila Bay, West York Is, Mindanao E | 4 | AD 762 424 |
| | 17-20 | Mindanao W, Balabac Strait, Brunei NW, Saigon 300 SE | 5 | AD 762 425 |
| HAWAIIAN AND SELECTED NORTH PACIFIC ISLAND COASTAL MARINE AREAS | | | | |
| Areas | 1-4 | Hawaiian-Windward, Leeward, Barking Sands, French Frig Shoals | 1 | AD 723 798 |
| | 5-7 | Johnston Island, Midway I, Wake I | 2 | AD 725 137 |
| | 8-10 | Majuro, Kwajalein, Eniwetok | 3 | AD 725 138 |
| | 11-13 | Ponape, Truk, Pagan | 4 | AD 726 740 |
| | 14-17 | Saipan, Guam, Yap, Koror | 5 | AD 727 900 |
| JAPANESE AND KOREAN COASTAL MARINE AREAS | | | | |
| Areas | 1-3 | Kushiro, Tomakomai, Sendai | 1 | AD 757 107 |
| | 4-6 | Tokyo, Hachijo Jima, Nagoya | 2 | AD 754 773 |
| | 7-9 | Nobeoka, Yaku Shima, Amami O, Shima | 3 | AD 753 468 |
| | 10-12 | Okinawa, Sakishima I, South East China Sea | 4 | AD 753 216 |
| | 13-15 | Central, North East China Sea, Nagasaki | 5 | AD 743 488 |
| | 16-18 | Sasebo, Inland Sea, Matsue | 6 | AD 743 944 |
| | 19-21 | Niigata, Akita, Hakodate | 7 | AD 742 797 |
| | 22-24 | Central, Southern Sea of Japan, Wonsan | 8 | AD 733 997 |
| | 25-27 | Kangnung, Pusan, Cheju Island | 9 | AD 732 758 |
| | 28-30 | Southern Yellow Sea, Inch'on, Korea Bay | 10 | AD 730 957 |
| | 31-33 | Bonin Islands, Volcano Islands, Marcus I | 11 | AD 730 958 |
| SIBERIAN COASTAL MARINE AREAS | | | | |
| Areas | 1-7 | Wrangel Is, SW Chukchi Sea, Anadyrskiy Gulf, Khatyrka-340S, karaginskiy Is, Kronotskiy Peninsula | 1 | AD-A016 251 |
| | 8-14 | Commander Is, Kuril Strait-W, E, 400E, Ckhotsk Sea N, NW, Shelikhova Gulf | 2 | AD-A016 687 |
| | 15-21 | Okhotsk Sea-NE, SW, SE, W Coast Kamchatka, Tatar Strait-N, S, Sakhalin Island SE | 3 | AD-A016 913 |
| | 22-28 | Onekotan Is-SE, Soya Strait-W, E, Urup Is, Vladivostok, Sea of Japan N | 4 | AD-A018 623 |
| ALASKAN AND BRITISH COLUMBIAN COASTAL AREAS | | | | |
| Areas | 1-3 | Vancouver, Queen Charlotte, Sitka | 11 | AD 716 721 |
| | 4-6 | Cordova, Seward, Kodiak | 12 | AD 717 360 |
| | 7-10 | Unimak, Dutch Harbor, Adak, Attu | 13 | AD 717 949 |
| | 11-13 | Bristol Bay, St Paul, St Paul 180W | 14 | AD 718 345 |
| | 14-18 | Nunivak, St Matthew, St Lawrence, Cape Lisburne, Barrow | 15 | AD 718 346 |

| Summary of Synoptic Meteorological Observations | | Vol. No. | Accession No. |
|---|---|---|---|
| **NORTH AMERICAN COASTAL MARINE AREAS (Volumes 1-6 Revised)** | | | |
| Areas 1-7 | Belle Isle Strait, OSV Bravo, NE & SE Newfoundland Coast, Placentia Bay S, Cabot Strait, Anticosti Is | 1 | AD-A006 990 |
| 8-14 | St. Lawrence River, Gulf of St Lawrence, Cape Breton Is SE, Halifax, Boston, Quonset Point, New York | 2 | AD-A008 666 |
| 15-21 | Atlantic City, Norfolk, Cape Hatteras, Bermuda, Charleston, Jacksonville, Miami | 3 | AD-A008 816 |
| 22-29 | Guantanamo, Key West, Fort Myers, Apalachicola, Pensacola, New Orleans, Galveston, Corpus Christi | 4 | AD-A008 889 |
| 30-35 | Baja, San Diego, Santa Rosa I, Point Mugu, San Francisco | 5 | AD-A022 575 |
| 36-41 | Point Arena, Eureka, Cape Blanco, Newport, Astoria Vancouver Is SW | 6 | AD-A022 578 |
| **CARIBBEAN AND NEARBY ISLAND COASTAL MARINE AREAS** | | | |
| Areas 1-6 | British Honduras, Ciudad Del Carmen, Veracruz, Cape rojo, Yucatan, Isle of Pines | 1 | AD 787 723 |
| 7-11 | Cayman, Jamaica-West, South, North, Southeast | 2 | AD-A001 031 |
| 12-17 | Hispaniola S, Windward Pass, Grand Bahama, Nassau San Salvador, Acklins Island | 3 | AD-A001 912 |
| 18-23 | Hispaniola N, Santo Domingo, Mona Passage, Puerto Rico, PR South, PR North, Vieques | 4 | AD-A001 457 |
| 24-29 | Virgin Is, Leeward Is, Windward Is, Trinidad, Barcelona, Caracas | 5 | AD-A001 918 |
| 30-35 | Gulf of Venezuela, Riohacha, Cartagena, Colon, Gulf of Panama, Galapagos Islands | 6 | AD-A001 973 |
| **SOUTH AMERICAN COASTAL MARINE AREAS** | | | |
| Areas 1-8 | Georgetown, Cayenne, Amazon Delta, Fortaleza NW, Natal, Recife, Salvador, Victoria NE | 1 | AD-A039 971 |
| 9-16 | Rio De Janeiro, Florianopolis, Porto Alegre, Buenos Aires, Bahia Blanca, Rawson, Puerto Deseado, Magellan Strait East | 2 | AD-A039 972 |
| 17-24 | Tierra Del Fuego, Falkland Islands, South Georgia Tristan da Cunha Group, Trindade, St Helena, Ascension, St Peter and Paul Rocks | 3 | AD-A040 487 |
| **WEST AFRICAN AND SELECTED ISLAND COASTAL MARINE AREAS** | | | |
| Areas 1-8 | Azores, Madeira Islands, Casablanca SW, Canary I Central Spanish Sahara, Cape Blanc, Cape Verde I, Dakar | 1 | AD-A031 778 |
| 9-15 | Conakry, Monrovia, Ivory Coast, Accra, Gulf of Guinea East, Luanda NW, Lobito | 2 | AD-A031 779 |
| 16-22 | Skeleton Coast, Walvis Bay SW, Alexander Bay SW, Cape Town, Port Elizabeth, East London, Durban | 3 | AD-A032 604 |

| Summary of Synoptic Meteorological Observations | | | Vol. No. | Accession No. |
|---|---|---|---|---|
| MEDITTERRANEAN MARINE AREAS | | | | |
| Areas | 1-3 | Rota, Tangier, Malaga | 1 | AD 713 992 |
| | 4-7 | Oran, Cartagena, Barcelona, Marseille | 2 | AD 714 288 |
| | 8-11 | N. Menorca, Mallorca, Algeries, Corsica | 3 | AD 713 779 |
| | 12-15 | Sardinia, Annaba, Rome, S. Tyrrhenian Sea | 4 | AD 713 780 |
| | 16-19 | SW Sicily, Tripoli, N., S. Adriatic Sea | 5 | AD 713 648 |
| | 20-23 | W, E Ionian Sea, Malta, Gulf of Sidra | 6 | AD 713 295 |
| | 24-27 | N, S Agean Sea, Crete, Benghazi | 7 | AD 713 084 |
| | 28-31 | Rhodes, Central Levantine Basin, Alexandria, N. Cyprus | 8 | AD 713 085 |
| | 32-35 | S. Cyprus, Nile Delta, Beirut, Port Said | 9 | AD 712 761 |
| WESTERN EUROPEAN COASTAL MARINE AREAS | | | | |
| Areas | 1-6 | Lisbon, Aveiro, Porto La Coruna, Bijon, Bordeaux | 1 | AD 773 141 |
| | 7-11 | Nantes, Plymouth, English Channel, Cover Strait, Bristol Channel | 2 | AD 773 594 |
| | 12-17 | Irish Sea, Cork, SW-W Irish Coast, Scottish Sea, Outer Hebrides | 3 | AD 775 177 |
| | 18-23 | Shetland Is NW, Orkney Is, Edinburgh, Grimsby, Rhine Delta, Bremerhaven | 4 | AD 775 435 |
| | 24-30 | Esbjerg, Dogger Banks, North Sea, Shetland Is SE, Stavanger, Bergen, Alesund | 5 | AD 776 396 |
| | 31-36 | Olso, Copenhagen, Bornholm Is, Gulf of Danzig, Stockholm, Gulf of Riga | 6 | AD 777 049 |
| | 37-43 | Gulf of Finland, Gulf of Bothina S, N. Murmansk, Andenes, Central Norwegian Coast, OSV Mike | 7 | AD 777 133 |
| | 44-50 | Iceland SE, NW, N, NE, Reykjavik, Angmagssalik, Cape Farewell SE | 8 | AD 777 601 |

Climatological Publications

U.S. Navy Marine Climatic Atlas of the World

1. Volume I, North Atlantic Ocean (Revised December 1974), NAVAIR 50-1C-528 (GPO Stock #008-042-00064-1 $23.90)

2. Volume II, North Pacific Ocean (Revised March 1977) NAVAIR 50-1C-529 (GOP Stock #008-042-00068-3 $27.50)

3. Volume III, Indian Ocean (Revised March 1976) NAVAIR 50-1C-530 (GPO Stock #008-042-00066-7 $21.00)

4. Volume IV, South Atlantic Ocean (September 1958) NAVAIR 50-1C-531 Note: A revised edition is scheduled for distribution in mid-1978.

5. Volume V, South Pacific Ocean (November 1959), NAVAER 50-1C-532 Note: A revised edition is scheduled for 1980.

6. Volume VI, Arctic Ocean (February 1963), NAVWEPS 50-1C-533

7. Volume VII, Antarctic (September 1965), NAVWEPS 50-1C-50

8. Volume VIII, The World (March 1969) NAVAIR 50-1C-54

Other climatological or related publications

1. State of the Sea Photographs of the Beaufort Wind Scale (July 1971) NAVAIR 50-1P-4

2. International Meteorological Codes 1974 and Worldwide Synoptic Broadcasts (January 1975) NAVAIR 50-1P-11

3. Guide to Standard Weather Summaries and Climatic Services (January 1975) NAVAIR 50-1C-534 (Also PB 221-354)

4. Upper Wind Statistics Charts of the Northern Hemisphere

   Volume 1, 850, 700 & 500 mb levels (August 1959) NAVAER 50-1C-535

   Volume II, 300, 200 & 100 mb levels ( August 1959) NAVAER 50-1C-535

   Volume III, 50 mb level (March 1962) NAVWEPS 50-1C-535

5. Components of the 1000 mb winds of the Northern Hemisphere (September 1966) NAVAIR 50-1C-51

6. Selected Level, Heights, Temperatures and Dew Points for the Northern Hemisphere (January 1970) NAVAIR 50-1C-52

Special Marine Environmental Studies

The following studies were prepared by special request as approved by the Director, Naval Oceanography and Meteorology (formerly the Commander, Naval Weather Service Command).

1. Climatological Study, Southern California Operating Area (March 1971) AD-721 117

2. Northeast Atlantic Environmental Scenario (November 1973) AD-A002 067

3. Northeast Pacific Environmental Scenario (June 1974) AD-A781 673

4. Bermuda Environmental Scenario (November 1974) AD-A007 448

5. A Study of Fog and Stratus for Selected Cold Regions (December 1975) AD-A023 591

6. Climatic Study of the Near Coastal Zone, East Coast of U.S. (June 1976) AD-A024 991

7. Climatic Study of the Near Coastal Zone, West Coast of U.S. (June 1976) AD-A024 992